Jefferson Laboratory
Science Overview

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DOE/ONP S&T Review
May 9, 2012

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Outline

- JLab context in Nuclear Physics
- 12 GeV Physics Program
  - phenomenology
  - techniques (theory+exp)
  - standard model tests

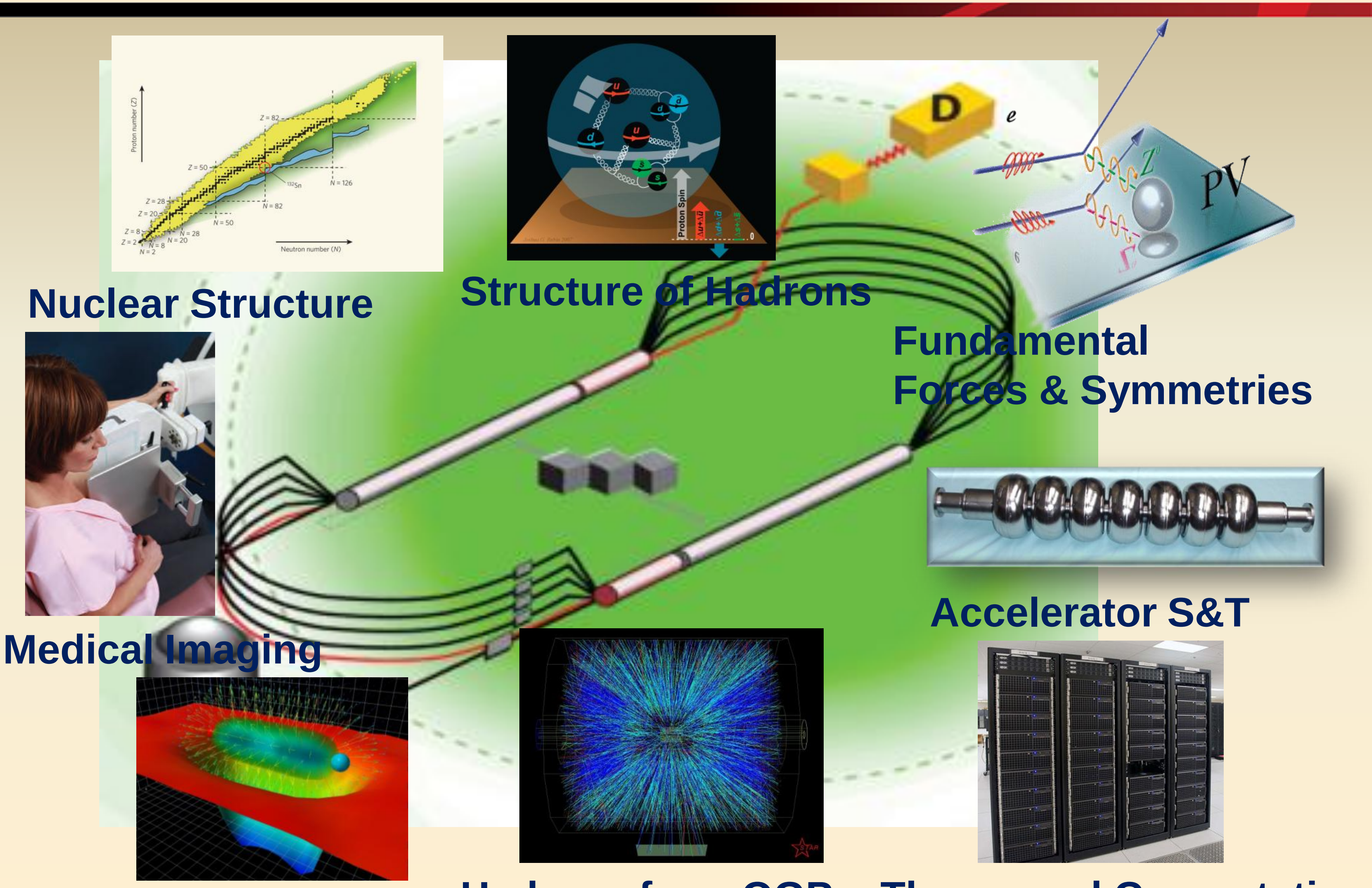
New

Discovery Potential

- MEIC
- Outlook

Note: Recent Accomplishments, Accelerator S&T, Theory/Computation to be covered in following talks

A Laboratory for Nuclear Science



Nuclear Structure

Structure of Hadrons

Fundamental Forces & Symmetries

Medical Imaging

Accelerator S&T

Quark Confinement

Hadrons from QGP

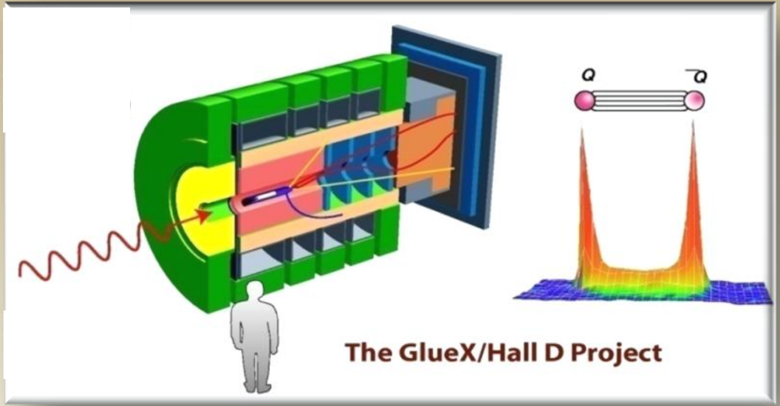
Theory and Computation

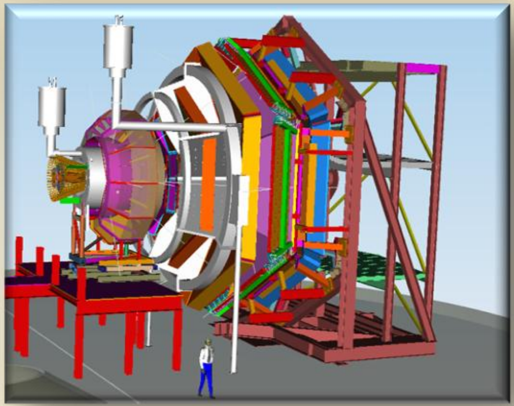
JLab: 21st Century Science Questions

- What is the role of gluonic excitations in the spectroscopy of light mesons? Can these excitations elucidate the origin of quark confinement?
- Where is the missing spin in the nucleon? Is there a significant contribution from valence quark orbital angular momentum?
- Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?
- What is the relation between short-range N-N correlations and the partonic structure of nuclei?
- Can we discover evidence for physics beyond the standard model of particle physics?

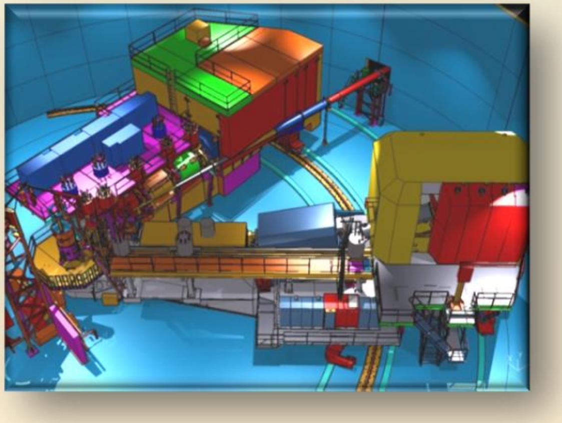
12 GeV Scientific Capabilities

Hall D – exploring origin of confinement by studying exotic mesons

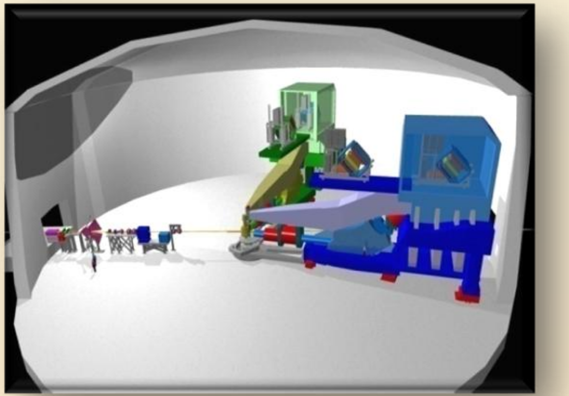




Hall B – understanding nucleon structure via generalized parton distributions



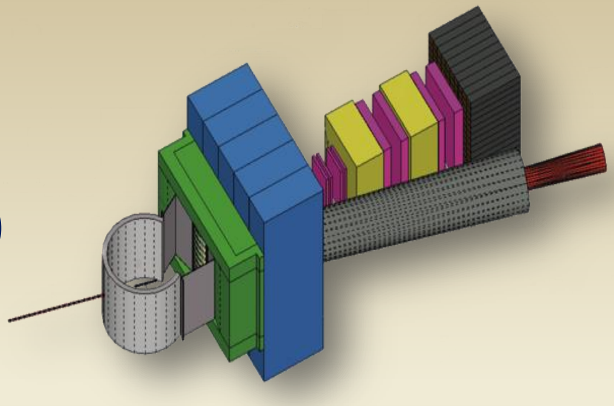
Hall C – precision determination of valence quark properties in nucleons and nuclei



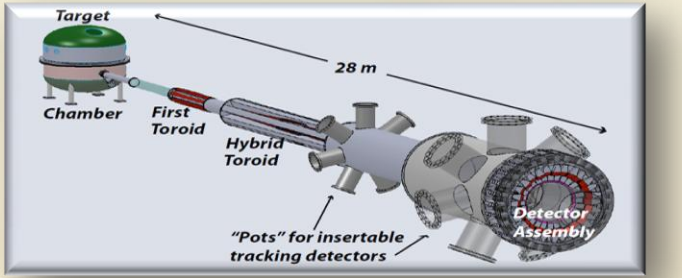
Hall A –form factors, future new experiments (e.g., PV and MOLLER)

Beyond 12 GeV Upgrade

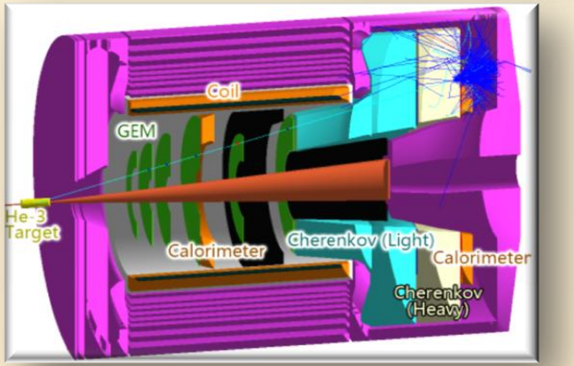
- **Super BigBite Spectrometer**
  (Approved for FY13-15 construction)



- **MOLLER experiment**
  (MIE – FY14-18?)



- **SoLID**
  Chinese collaboration
  CLEO Solenoid?



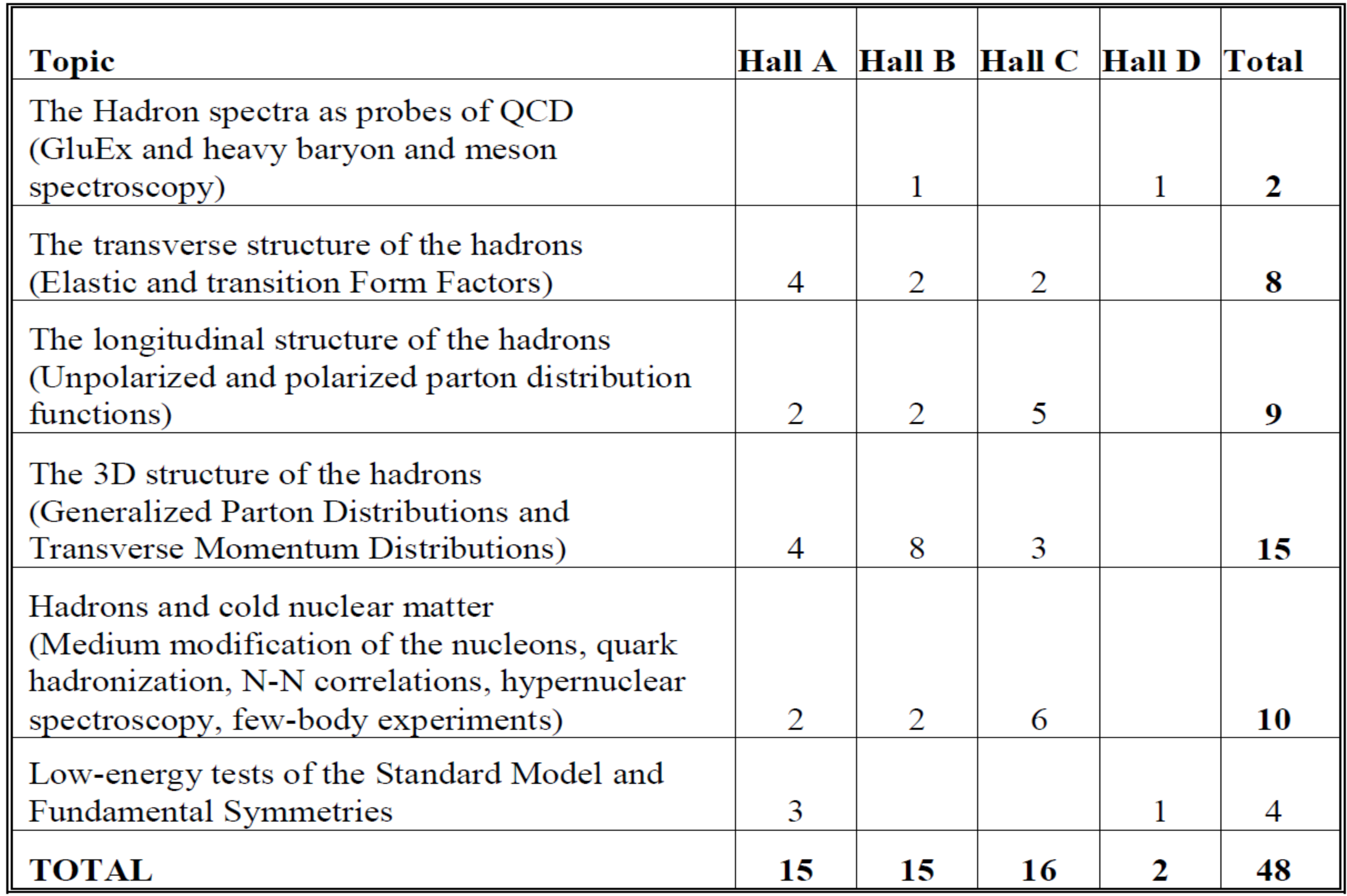
12 GeV Science Program

- The physical origins of quark confinement (GlueX, meson and baryon spectroscopy)
- The spin and flavor structure of the proton and neutron (PDF’s, GPD’s, TMD’s…)
- The quark structure of nuclei
- Probe potential new physics through high precision tests of the Standard Model

- Defining the Science Program:
  - Seven Reviews: Program Advisory Committees (PAC) - 2006 through 2011
  - Results: *48 experiments approved; 7 conditionally approved*
  - PAC39 scheduled June 2012
  - White paper for NSAC subcommittee (in progress)

Experiments for 4 Halls approved for
more than five years of operation beginning in FY15.

12 GeV Approved Experiments by Physics Topics



Topic	Hall A	Hall B	Hall C	Hall D	Total
The Hadron spectra as probes of QCD (GluEx and heavy baryon and meson spectroscopy)		1		1	**2**
The transverse structure of the hadrons (Elastic and transition Form Factors)	4	2	2		**8**
The longitudinal structure of the hadrons (Unpolarized and polarized parton distribution functions)	2	2	5		**9**
The 3D structure of the hadrons (Generalized Parton Distributions and Transverse Momentum Distributions)	4	8	3		**15**
Hadrons and cold nuclear matter (Medium modification of the nucleons, quark hadronization, N-N correlations, hypernuclear spectroscopy, few-body experiments)	2	2	6		**10**
Low-energy tests of the Standard Model and Fundamental Symmetries	3			1	4
TOTAL	**15**	**15**	**16**	**2**	**48**

E12-11-105 has not been counted with the experiments since it is considered a test

12 GeV Approved Experiments by PAC Days

(All approved experiments received scientific rating since last PAC)

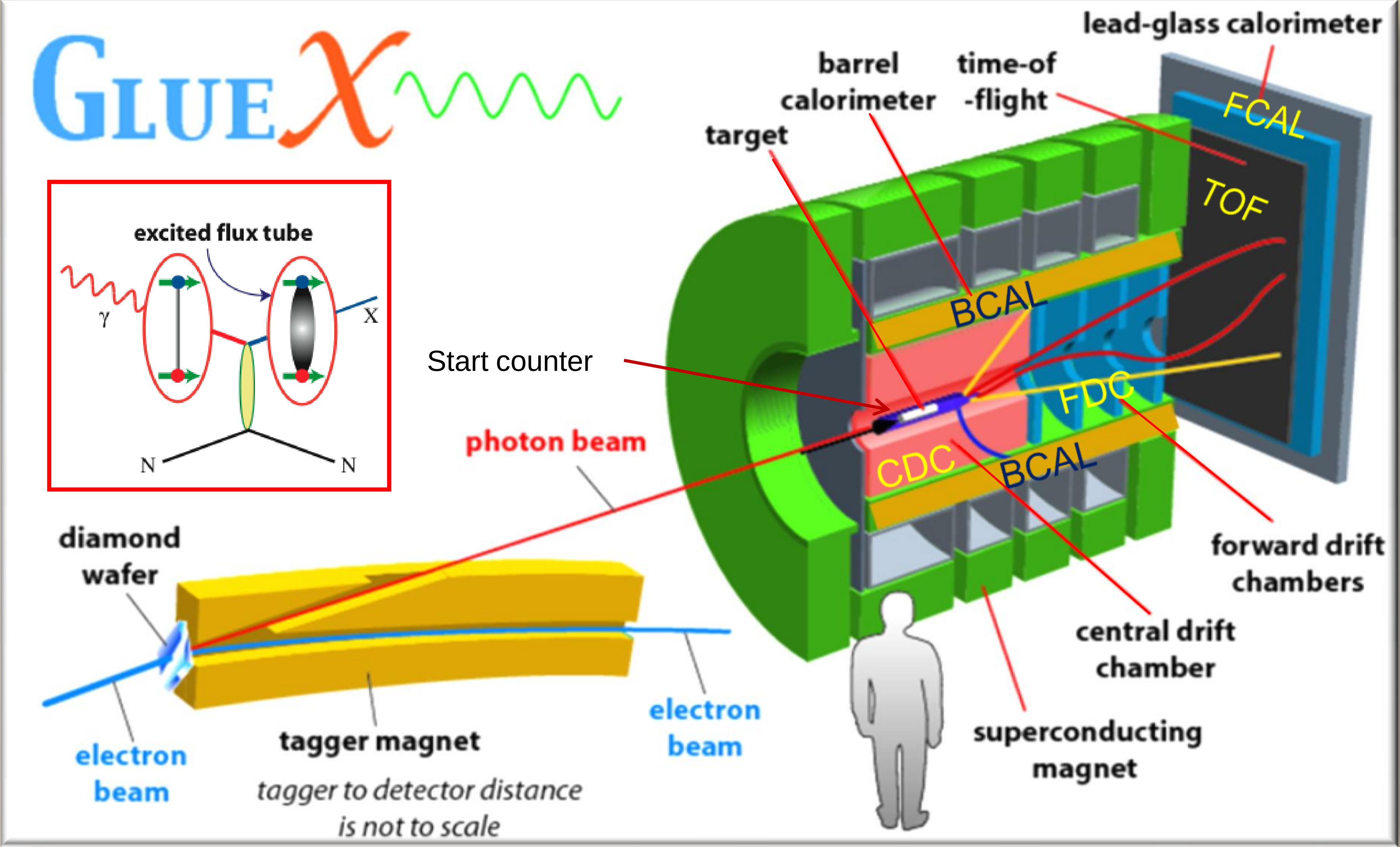
	Hall A	Hall B	Hall C	Hall D	Total
The Hadron Spectra as Probes of QCD (GluEx & heavy baryon and meson spectroscopy)		119		120	239
The Transverse Structure of the Hadrons (elastic and transition form factors)	144	70	102		316
The Longitudinal Structure of the Hadrons (Unpolarized and polarized parton distributions)	65	120	140		325
The 3D Structure of the Hadrons (GPDs and TMDs)	289	802	108		1199
Hadrons and Cold Nuclear Matter	54	120	179		353
Low-Energy Tests of the Standard Model and Fundamental Symmetries	547			79	535
Total	1099	1231	529	199	3058

- E12-11-105 has not been included here since it is an injector test experiment
- 638 PAC days in Hall A are associated with the Moller and SOLID programs

CLAS12 Experiments – Optimal Running

Proposal	Physics	Contact	Rating	Days	Group	all equipment available day 1	Energy	Group	Target
E12-07-104	Neutron magnetic form factor	G. Gilfoyle	A-	30	**90**	Neutron detector RICH IC	11	A	liquid D_2 target
PR12-11-109 (a)	Dihadron DIS production	Avakian							
E12-09-007a	Study of partonic distributions in SIDIS kaon production	K. Hafidi	A-	56					
E12-09-008	Boer-Mulders asymmetry in K SIDIS w/ H and D targets	M. Contalbrigo	A-	TBA					
11-003	DVCS on neutron target	S. Niccolai	A	90					
E12-06-108	Hard exclusive electro-production of π^0, η	P. Stoler	B	80	**119**	RICH IC Forward tagger	11, 8.8, 6.6	B	liquid H_2
E12-06-112	Probing the proton's quark dynamics in Semi-Inclusive pion production	H. Avakian	A	60					
E12-06-119	Deeply Virtual Compton Scattering	F. Sabatie	A	80					
E12-09-103	Excitation of nucleon resonances at high Q^2	R. Gothe	B+	40					
E11-005	Hadron spectroscopy with forward tagger	M. Battaglieri	A-	119					
PR12-11-103	DVMP of ρ , ω, φ	M. Guidal							
E12-06-106	Color transparency in exclusive vector meson electroproduction off nuclei	K. Hafidi	B+	60	**60**		11	C	Nucllear targets
E12-06-117	Quark propagation and hadron formation	W. Brooks	A-	60	**60**		11	D	Nuclear
E12-10-102	Free Neutron structure at large x	S. Bueltman	A	40	**40**	Radial TPC	11	E	Gas D_2
E12-06-109	Longitudinal Spin Structure of the Nucleon	S. Kuhn	A	80	**170**	Polarized target RICH IC	11	F	NH_3 ND_3
E12-06- 119(b)	DVCS on longitudinally polarized proton target	F. Sabatie	A	120					
E12-07-107	Spin-Orbit Correl. with Longitudinally polarized target	H. Avakian		103					
PR12-11-109 (b)	Dihadron studies on long. polarized target	H. Avakian							
E12-09-007(b)	Study of partonic distributions using SIDIS K production	K. Hafidi	A-	110					
E12-09-009	Spin-Orbit correlations in K production w/ pol. targets	H. Avakian	A-	103					
PR12-11-109	SIDIS on transverse polarized target	M. Contalbrigo				Transverse target	11	G	HD
TOTAL run time				1231	**539**				

Hall D



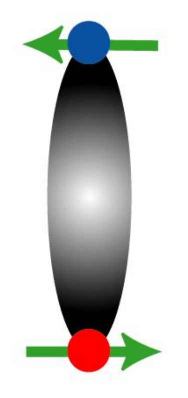
→ E. Chudakov talk

Quantum Numbers of Hybrid Mesons

Quarks ⊕ **Excited Flux Tube** → **Hybrid Meson**

$$S=0$$
$$L=0$$
$$J^{PC}=0^{-+}$$

like π, K

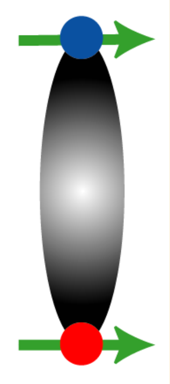


$$J^{PC}=\begin{cases}1^{+-}\\1^{-+}\end{cases}$$

$$J^{PC}=\begin{cases}1^{--}\\1^{++}\end{cases}$$

$$S=1$$
$$L=0$$
$$J^{PC}=1^{--}$$

like γ, ρ



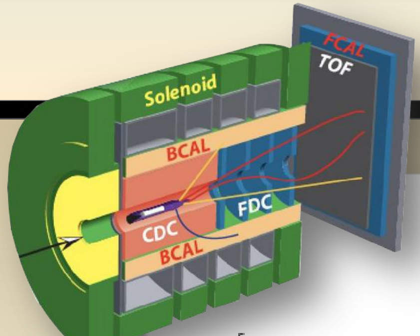
$$J^{PC}=\begin{cases}1^{+-}\\1^{-+}\end{cases}$$

Exotic

$$J^{PC}=\begin{cases}0^{-+} \quad \boxed{1^{-+}} \quad 2^{-+}\\ \boxed{0^{+-}} \quad 1^{+-} \quad \boxed{2^{+-}}\end{cases}$$

Flux tube excitation (and parallel quark spins) lead to exotic J^{PC}

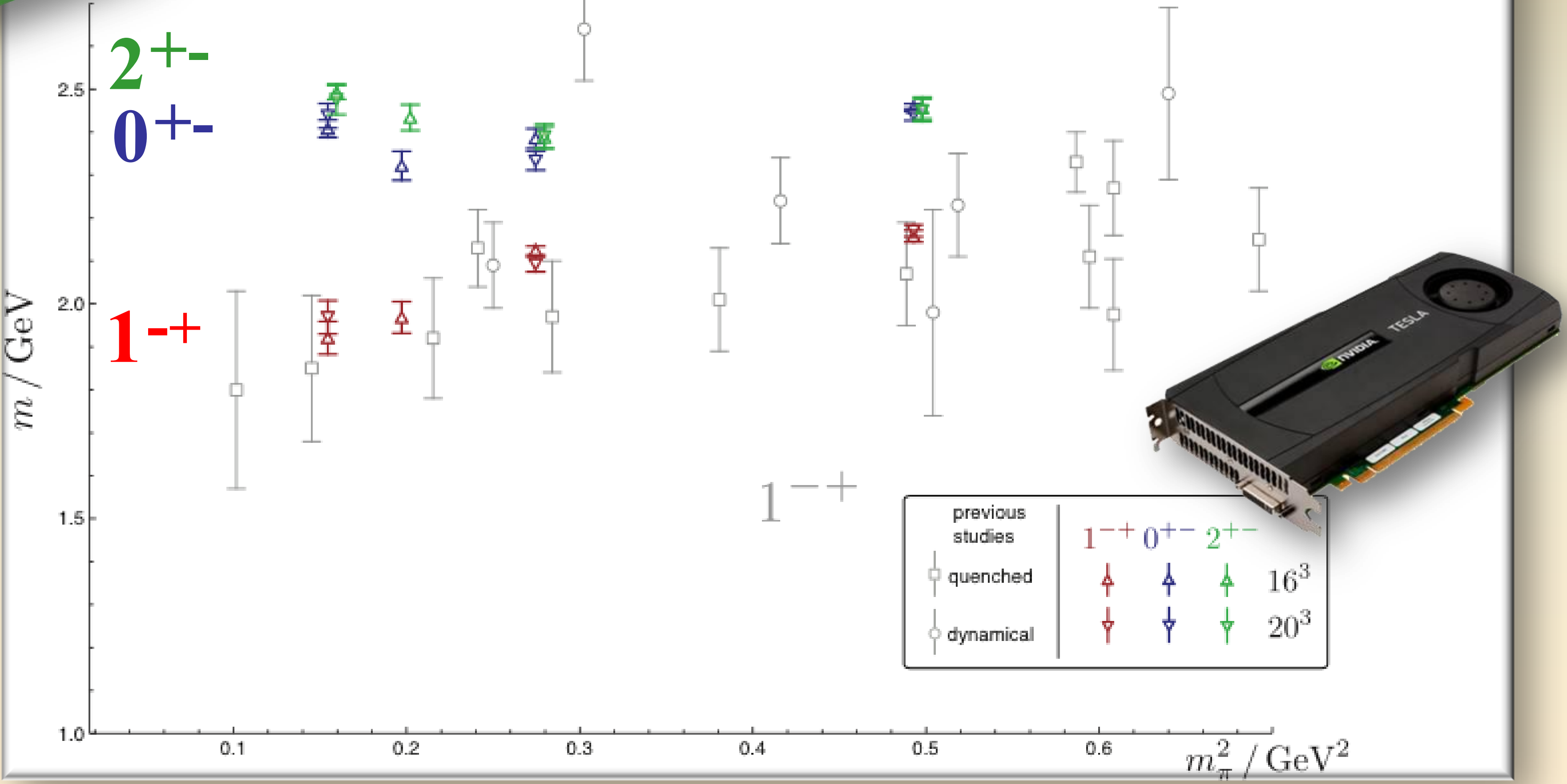
Isovector Meson Spectrum



GLUEX CITATIONS PERIMENT

Hall D@JLab

States with Exotic Quantum Numbers

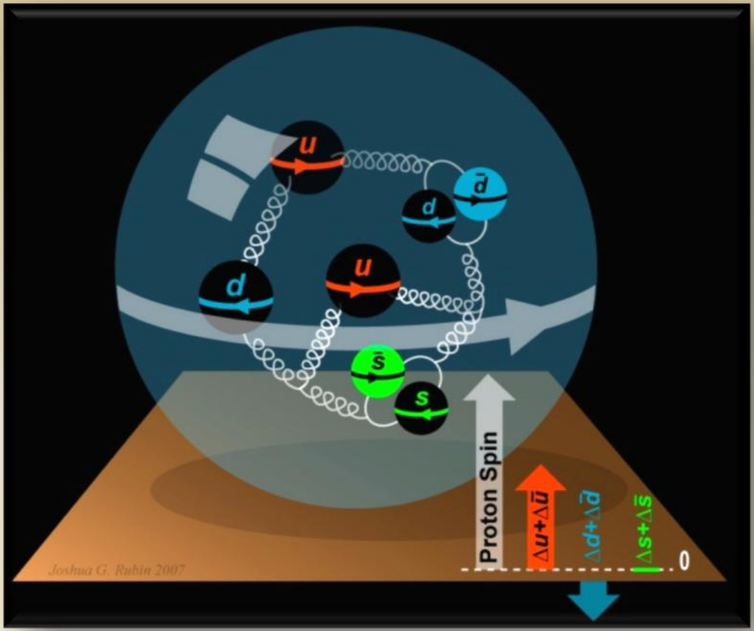


Dudek et al.

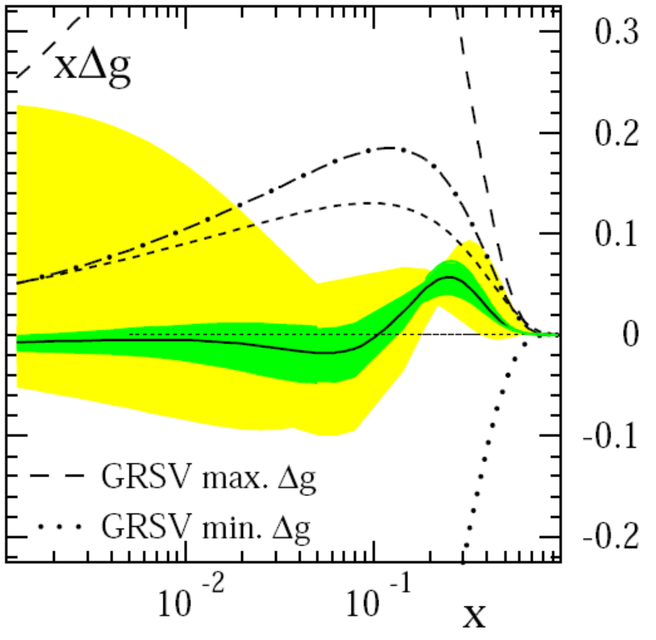
The Incomplete Nucleon: Spin Puzzle

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

[X. Ji, 1997]



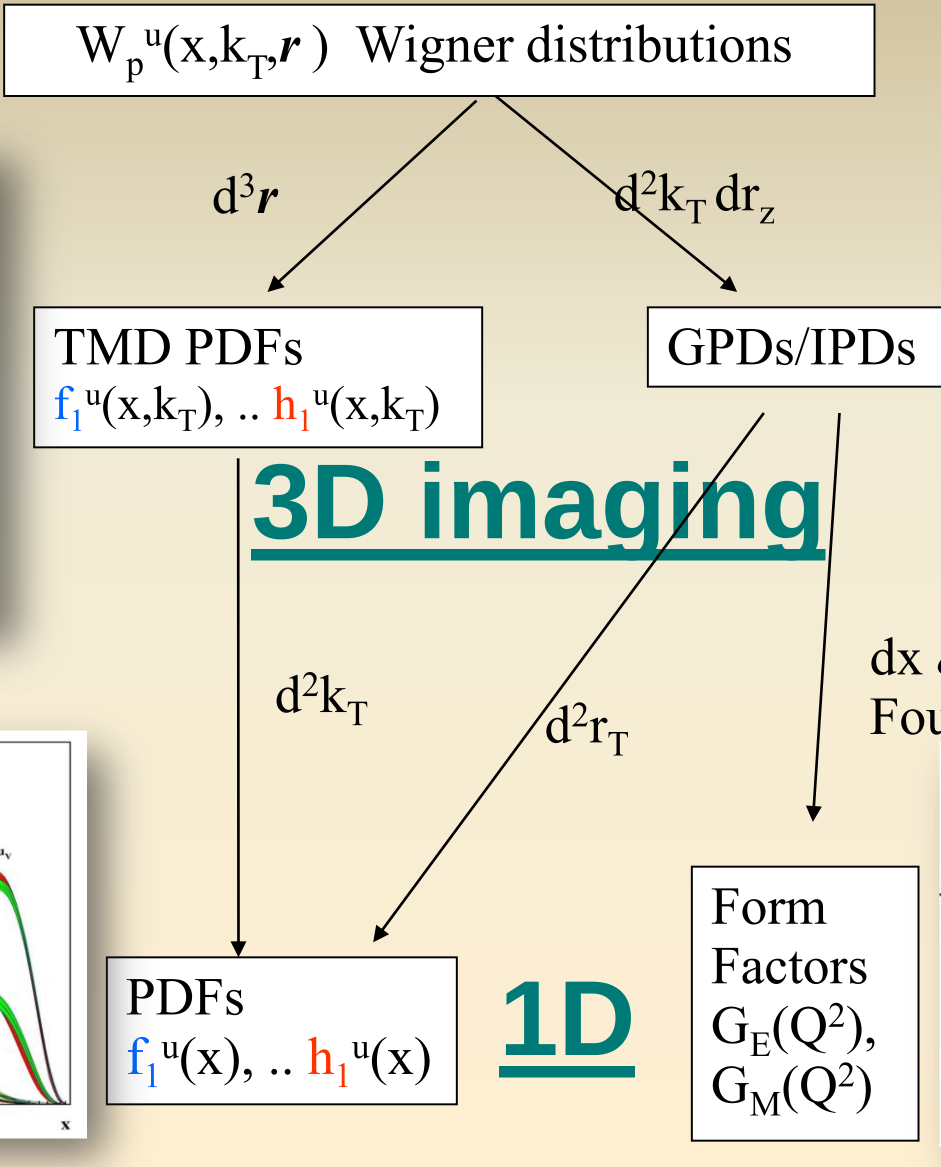
- **DIS → ΔΣ ≅ 0.25**
- **RHIC + DIS → ΔG« 1**
- **→ L_q**



D. de Florian et al., PRL 101 (2008) 072001

Unified View of Nucleon Structure

6D Dist.



$W_p^u(x,k_T,\boldsymbol{r})$ Wigner distributions

$d^3\boldsymbol{r}$

$d^2k_T\, dr_z$

TMD PDFs
$f_1^u(x,k_T)$, .. $h_1^u(x,k_T)$

GPDs/IPDs

3D imaging

d^2k_T

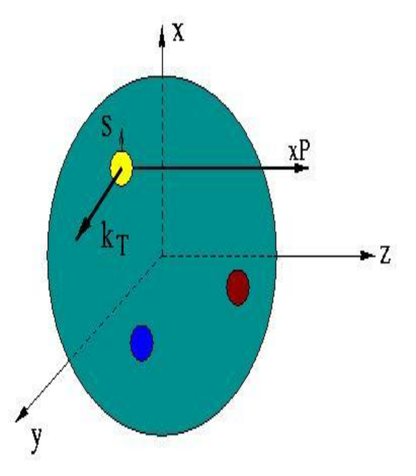
d^2r_T

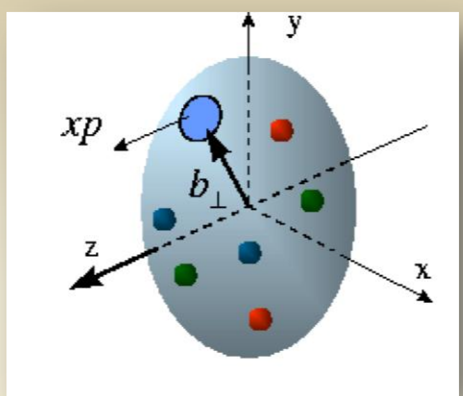
PDFs
$f_1^u(x)$, .. $h_1^u(x)$

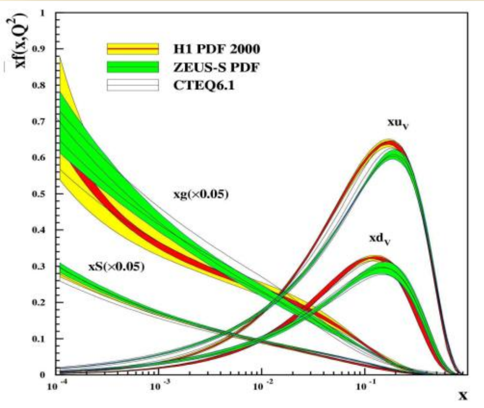
1D

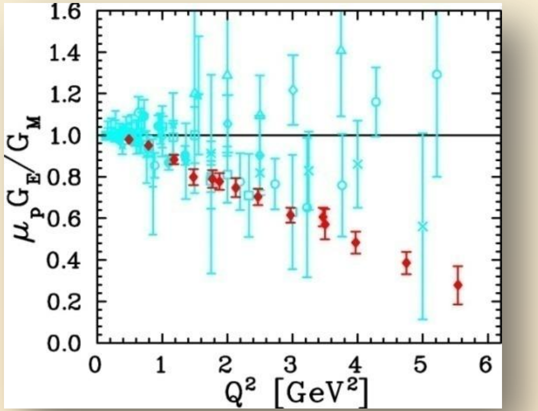
dx &
Fourier Transformation

Form
Factors
$G_E(Q^2)$,
$G_M(Q^2)$









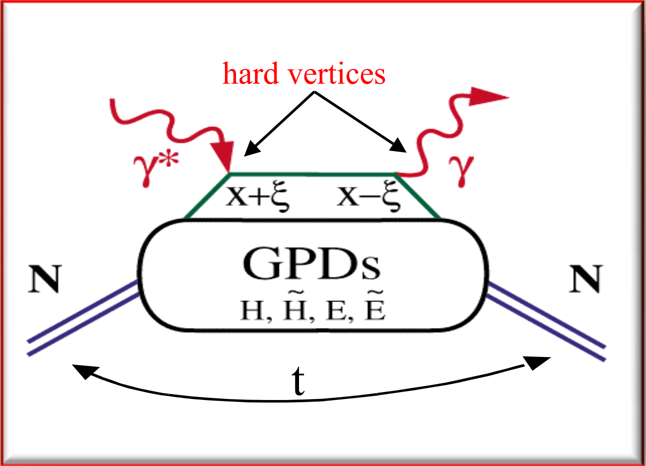
Extraction of GPD’s

→ F. X. Girod talk

Cleanest process: Deeply Virtual Compton Scattering

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{\Delta\sigma}{2\sigma}$$

$\xi = x_B/(2-x_B)$



Polarized beam, unpolarized target:

$\Delta\sigma_{LU} \sim \sin\phi\{F_1 H + \xi(F_1+F_2)\tilde{H} + kF_2 E\}d\phi$ ⇒ $H(\xi,t)$

Unpolarized beam, longitudinal target:

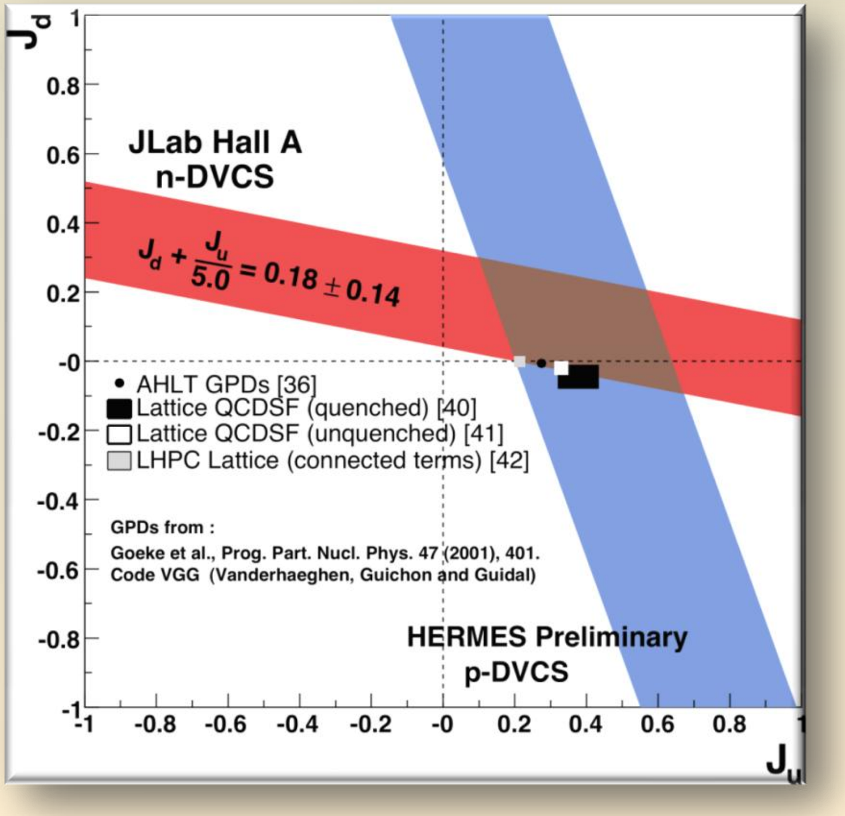
$\Delta\sigma_{UL} \sim \sin\phi\{F_1\tilde{H} + \xi(F_1+F_2)(H + \xi/(1+\xi)E)\}d\phi$ ⇒ $\tilde{H}(\xi,t)$

Unpolarized beam, transverse target:

$\Delta\sigma_{UT} \sim \sin\phi\{k(F_2 H - F_1 E)\}d\phi$ ⇒ $E(\xi,t)$

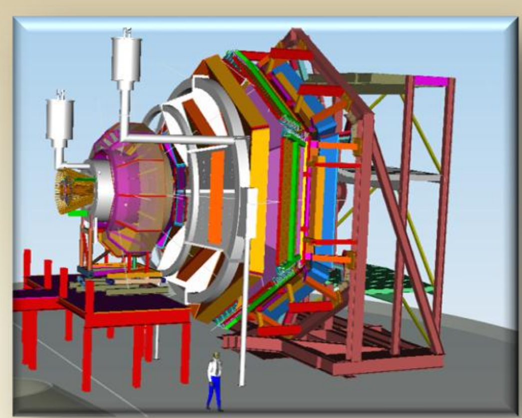
Quark Angular Momentum

$$J^q(t) = \int_{-1}^{+1} dx x[H^q(x,\xi,t) + E^q(x,\xi,t)]$$



→ **Access to quark orbital angular momentum**

DVCS beam asymmetry at 12 GeV CLAS12

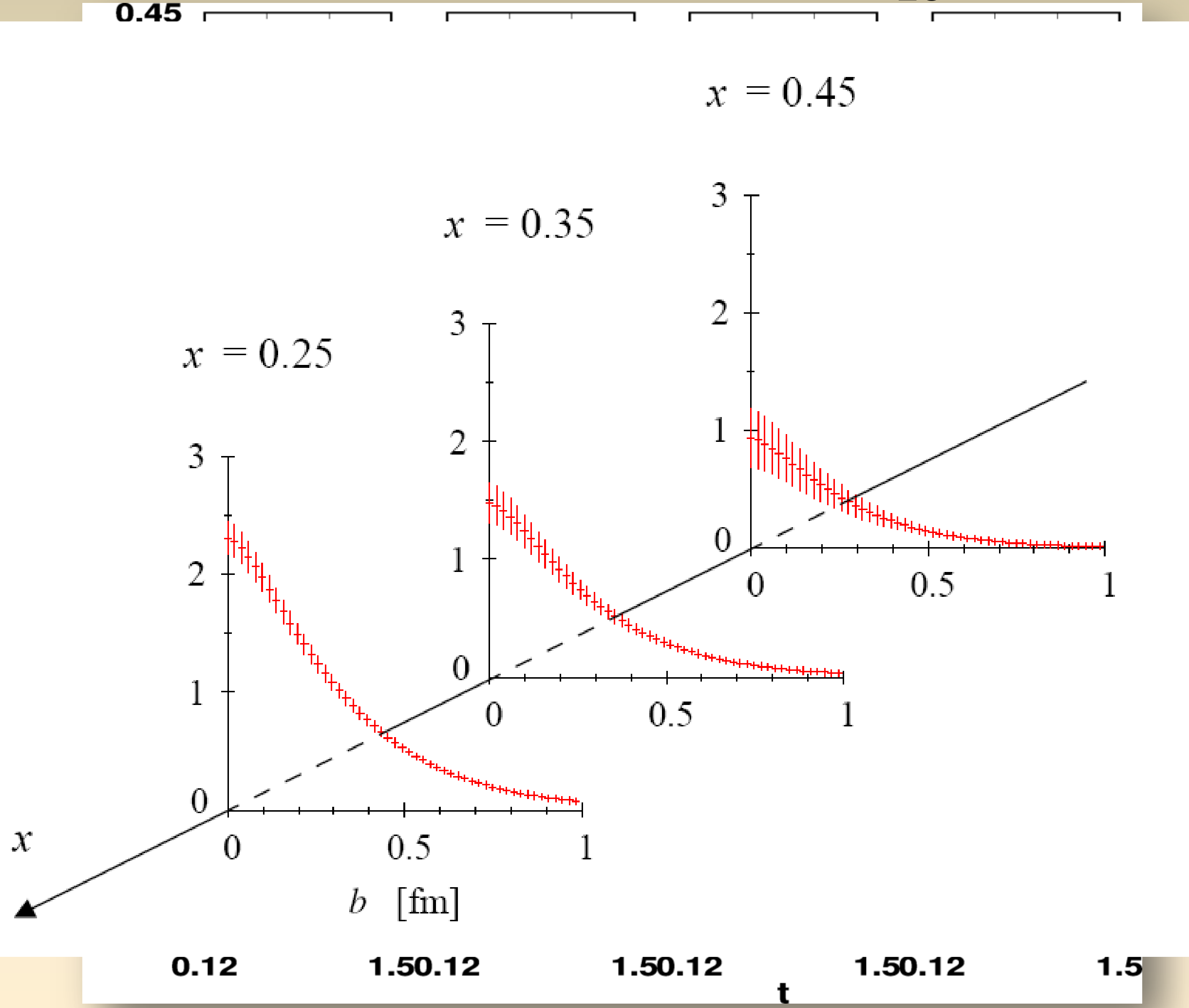


$\vec{e}p \longrightarrow ep\gamma$

High luminosity and large acceptance allows wide coverage in $Q^2 < 8$ GeV^2, $x_B < 0.65$, and $t < 1.5$GeV^2

→ F. X. Girod talk

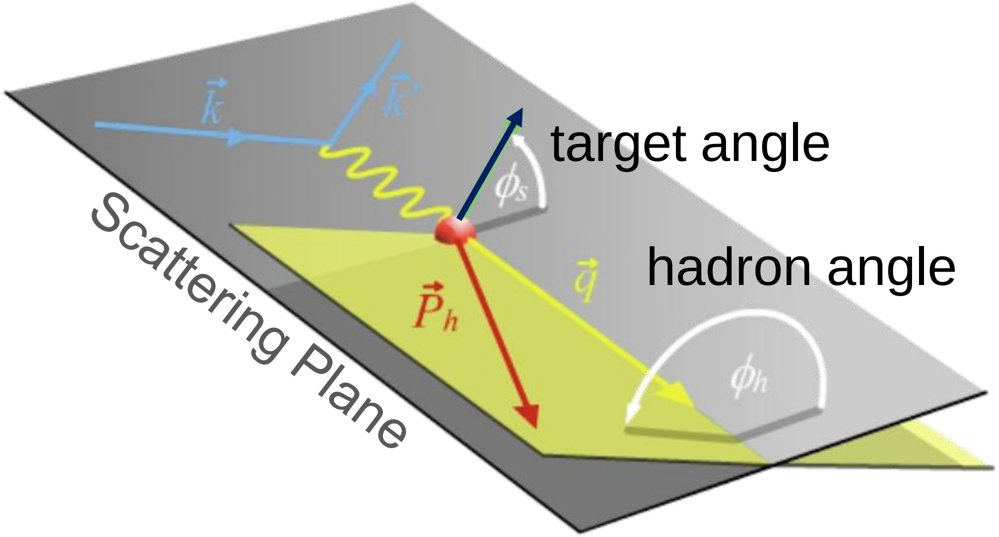
sinφ moment of A_{LU}



SIDIS Electroproduction of Pions

- Separate Sivers and Collins effects

→ **K. Allada talk**



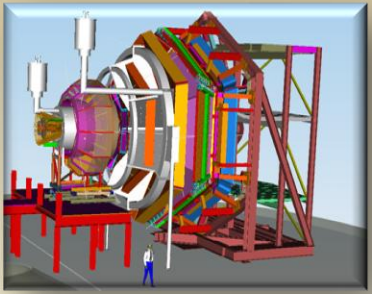
- Previous data from HERMES,COMPASS
- New landscape of TMD distributions
- Access to orbital angular momentum

- **Sivers** angle, effect in distribution function: **(ϕ_h-ϕ_s)**
- **Collins** angle, effect in fragmentation function: **(ϕ_h+ϕ_s)**

SIDIS Studies with 12 GeV at JLab

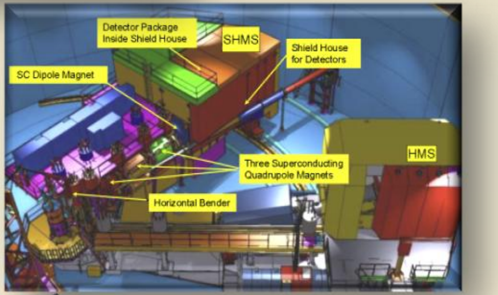
- **CLAS12 in Hall B**

  General survey, medium lumi



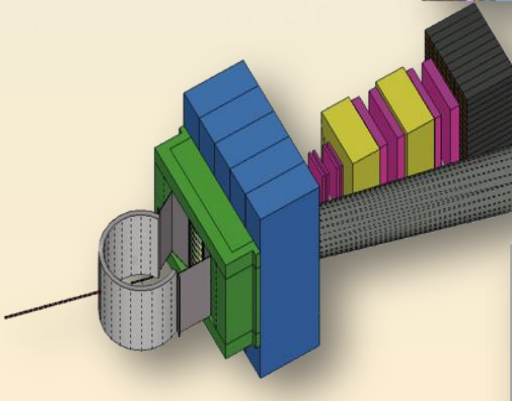
- **SHMS- HMS in Hall C**

  L-T studies, precise π^+/π^- ratios



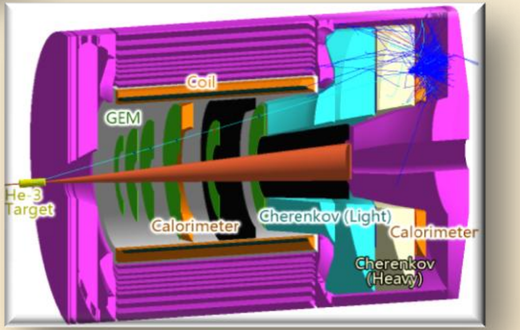
- **SBS in Hall A**

  High x, High Q^2, 2-3D



- **SOLID in Hall A**

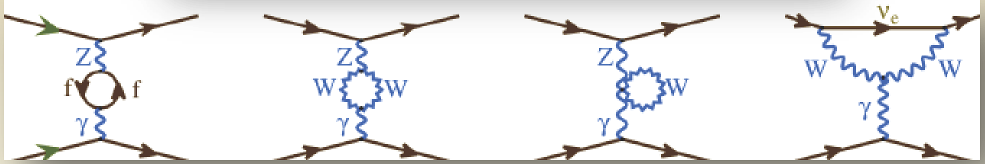
  High Lumi and acceptance – 4D

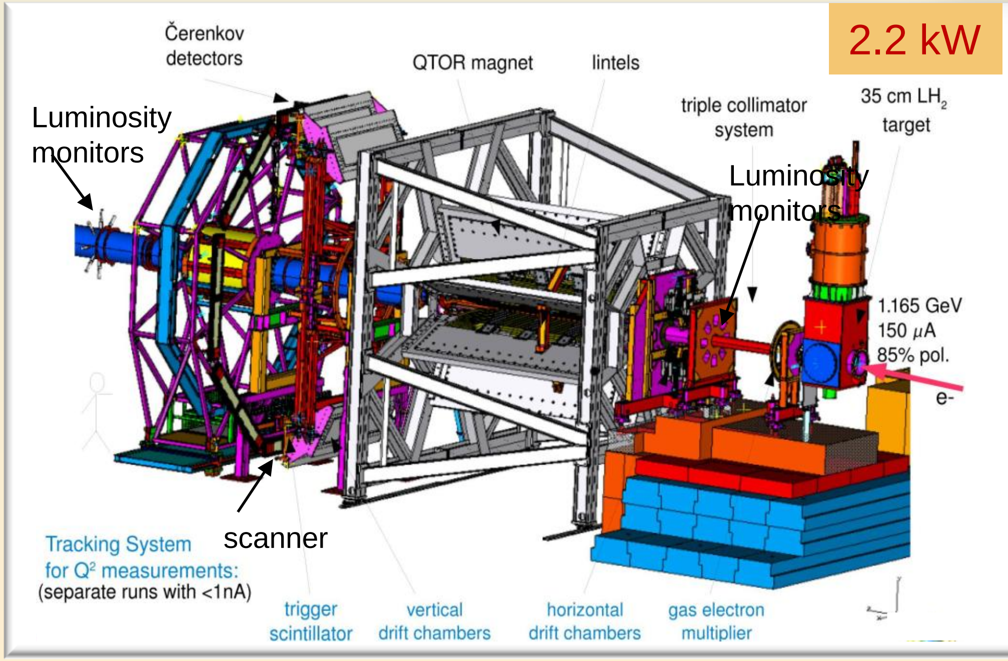


Qweak

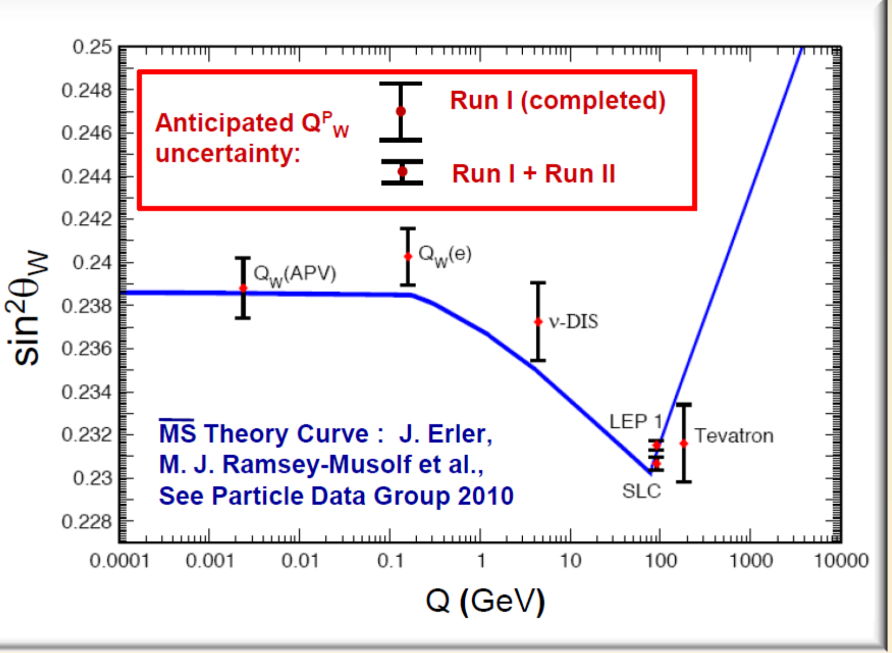
Precise determination of the weak charge of the proton

$$Q_w = -2(2C_{1u}+C_{1d})$$
$$=(1 - 4 \sin^2 \theta_W)$$

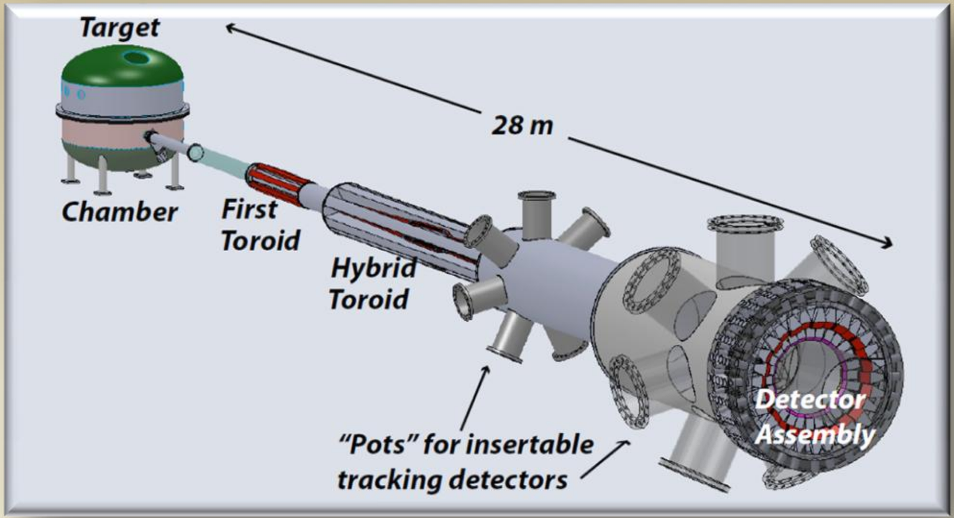




2.2 kW



Future PV Program at JLab



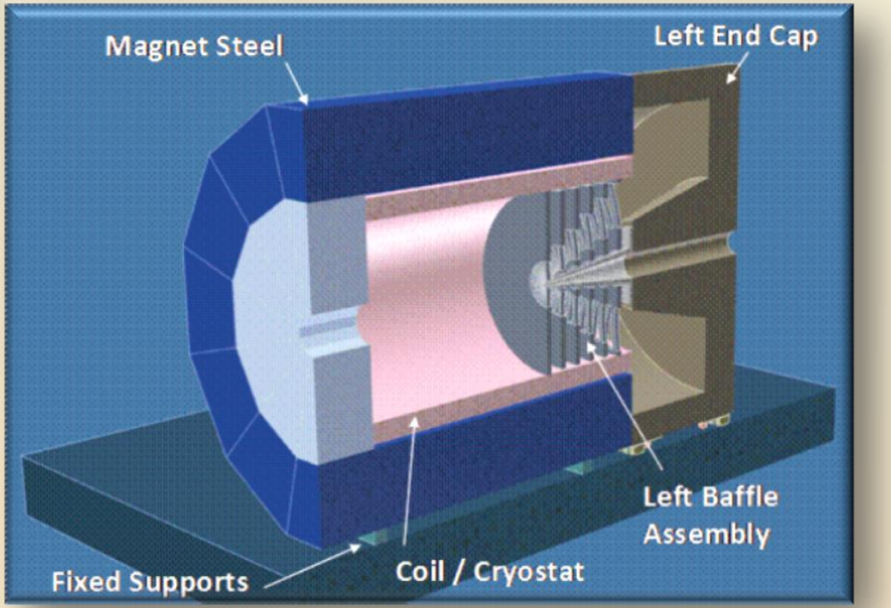
→ R. Michaels talk

PV Moller Scattering:

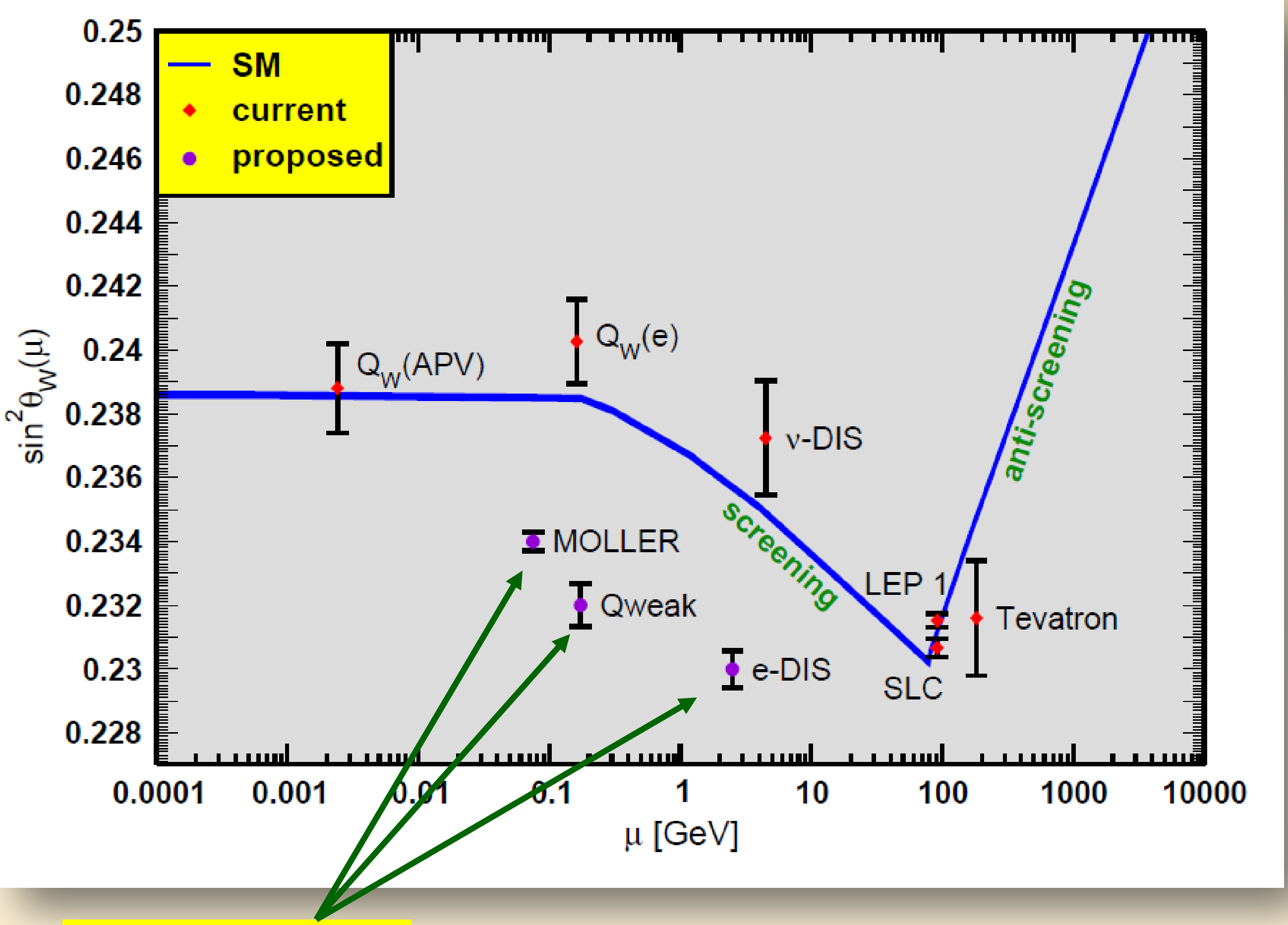
- Custom Toroidal Spectrometer
- 5kW LH Target

SOLID (PVDIS):

- High Luminosity on LD2 and LH2
- Better than 1% errors for small bins
- Large Q^2 coverage
- x-range 0.25-0.75
- $W^2 > 4$ GeV^2



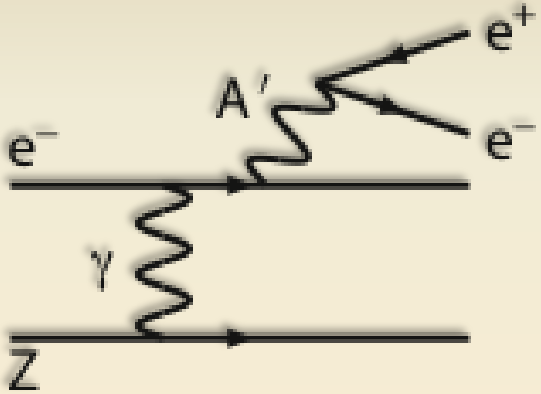
Projected Results

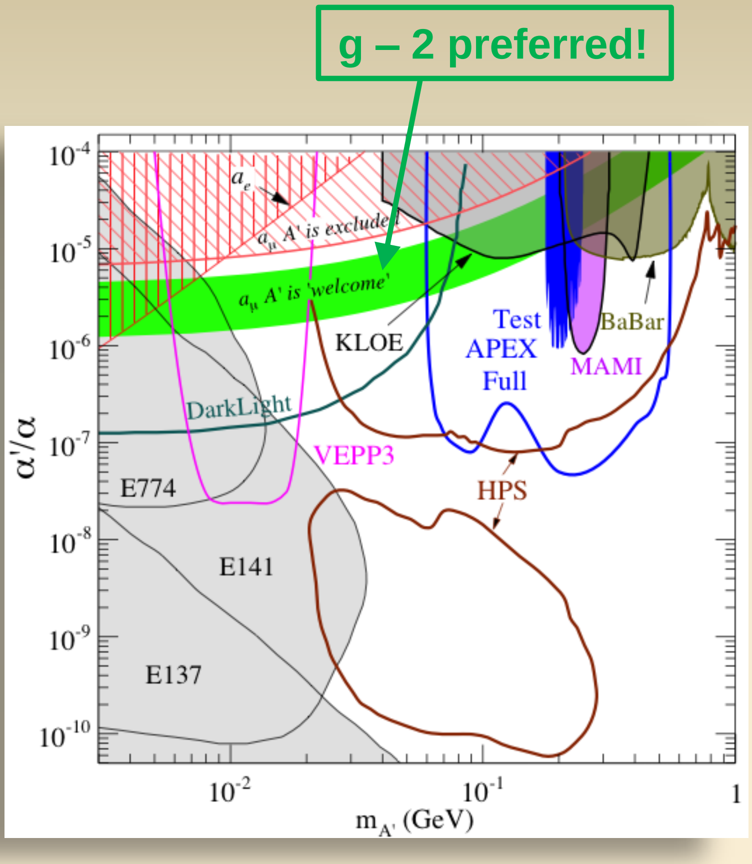


JLab program

New Opportunity: Search for A’ at JLab

Search for new forces mediated by ~100 MeV vector boson A’ with weak coupling to electrons:





g – 2 preferred!

- New ~GeV–scale force carriers are important category of physics beyond the SM
- Fixed-target experiments @JLab (FEL + CEBAF) have unique capability to explore this!

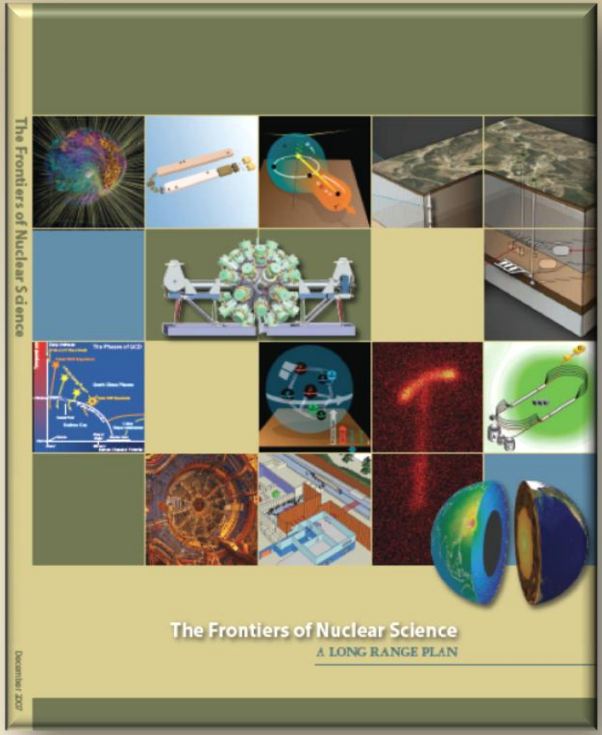
12 GeV JLab – The Potential

- Opportunity to discover and study new exotic mesons to elucidate the mechanism of confinement.
- Open a new landscape of nucleon tomography, with potential to identify the missing angular momentum.
- Establish the quantitative foundation for the short-distance behavior in nuclei, underpinning the development of precision nuclear structure studies.
- Provide stringent new tests of the standard model and extensions, complementing the information obtained at LHC.
- Establish a firm basis for higher energy studies with a future **Electron Ion Collider**

Electron Ion Collider

NSAC 2007 Long-Range Plan:

> “An **Electron-Ion Collider (EIC)** with **polarized** beams has been **embraced by the U.S. nuclear science community** as embodying the vision for **reaching the next QCD frontier**. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia.”

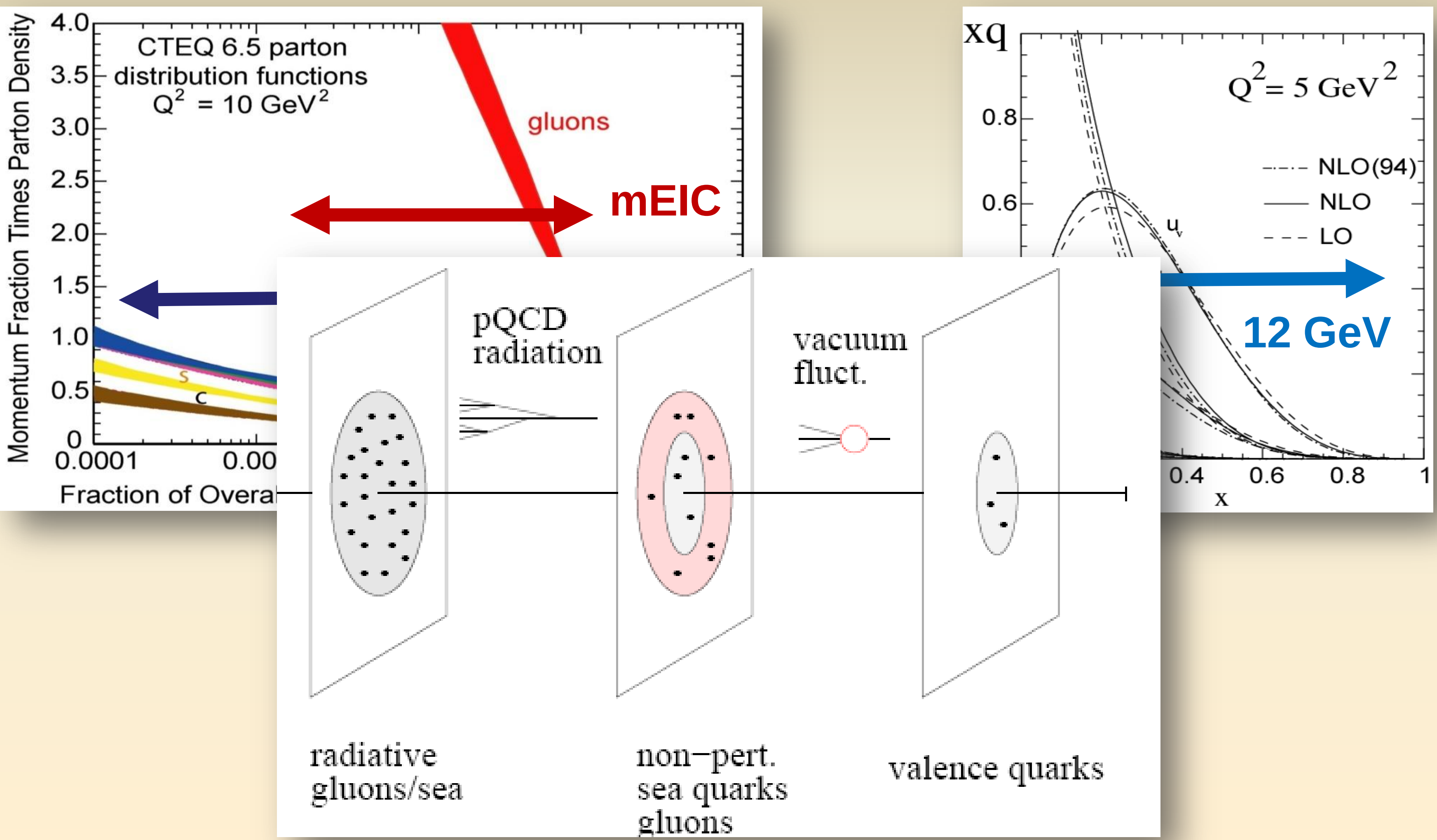


- **EIC “collaboration” – Milner & Deshpande contact persons, involves BNL and JLab communities**
- **JLab and BNL are both developing “staged” designs**
- **EICAC advisory comm. → Montgomery & Aronson (BNL)**
- **Next NSAC Long Range Plan?**

Into the "sea": EIC

→ **P. Nadel-Turonski talk**

- An EIC aims to study the sea quarks, gluons, and scale (Q^2) dependence.
- With 12 GeV we study mostly the valence quark component



EIC Science Frontier

Explore the nuclear landscape at low x to:

- **Discover the collective effects of gluons in nuclei**
- **Complete the map of the spin and spatial structure of sea quarks and gluons in nucleons**
- **Understand the emergence of hadronic matter from quarks and gluons**

EIC: JLab Community Leadership

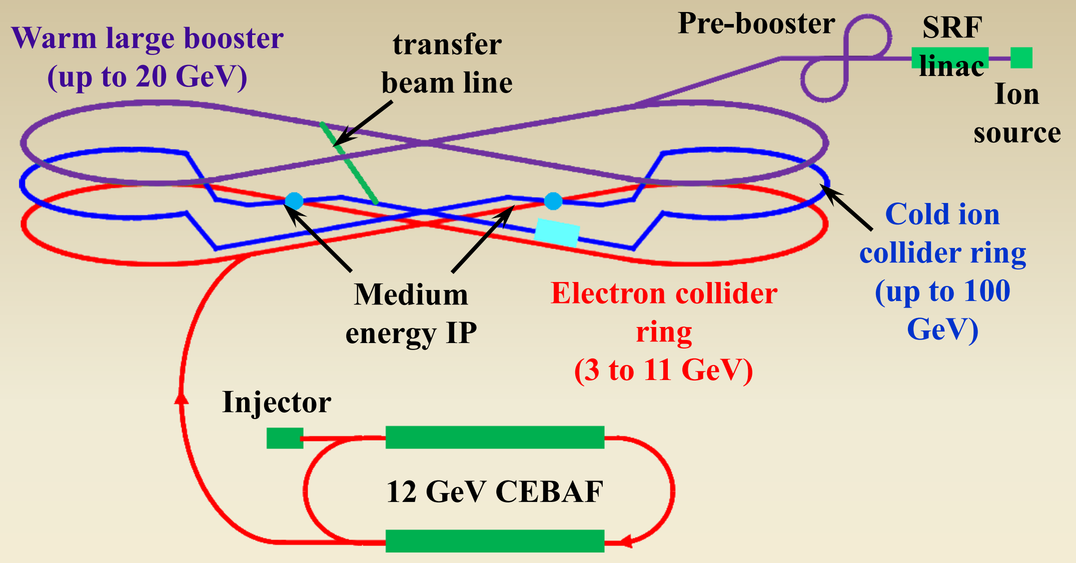
- 5 workshops in 2010 organized by JLab user community

- JLab users and staff participated in 2010 INT program

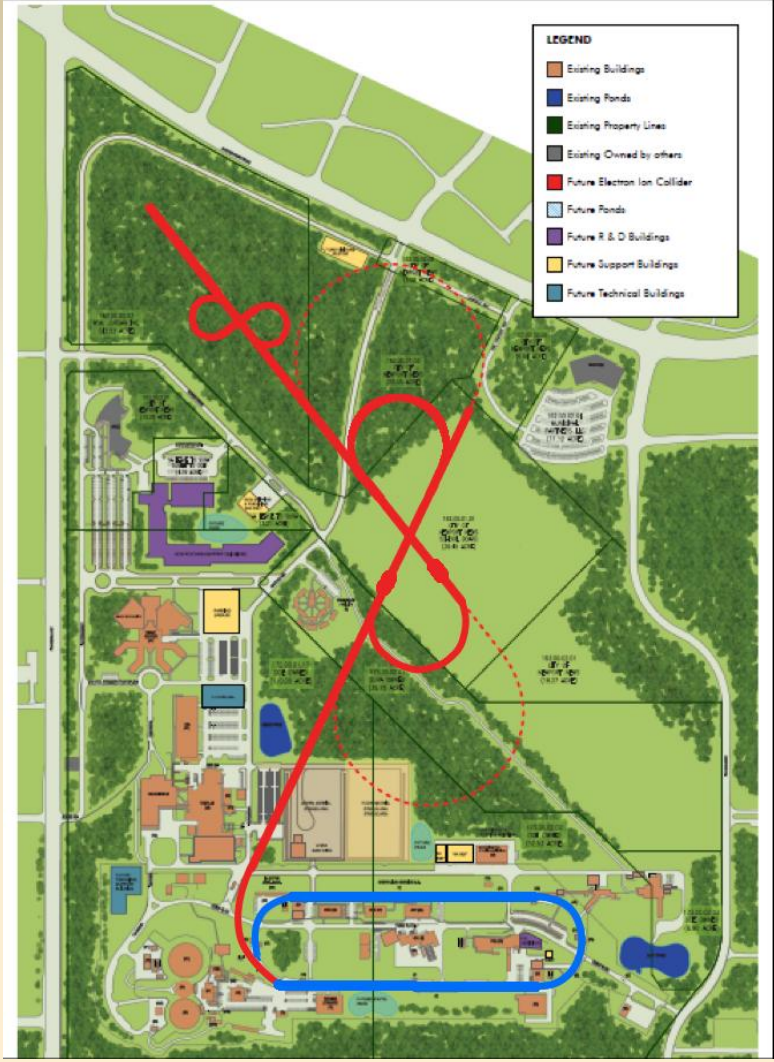
- We appointed JLab users as members of writers/editors of EIC white paper (in preparation)

- At JLab we have fostered a united effort with BNL-RHIC community to move the science case forward

Medium Energy EIC@JLab



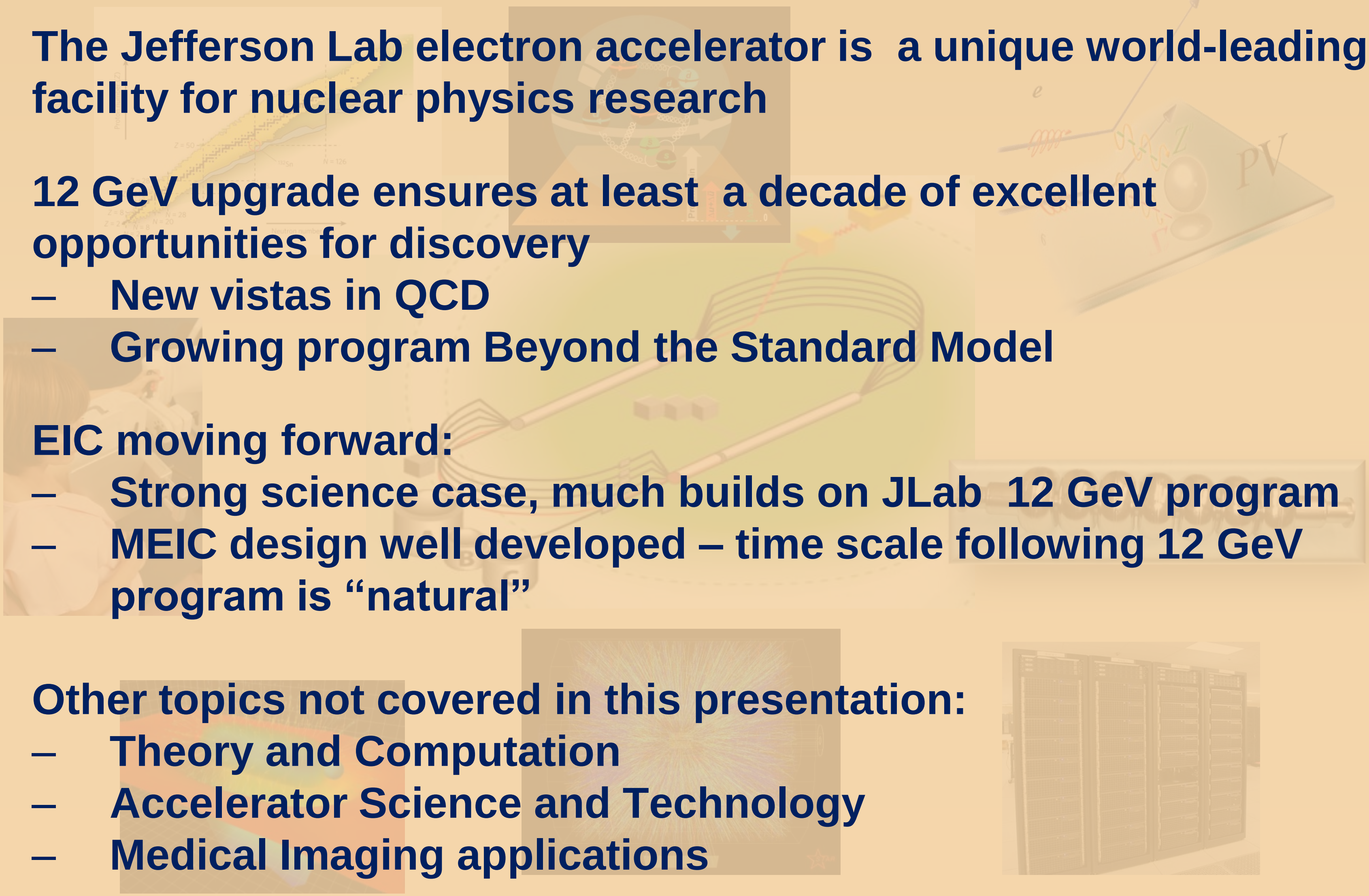
→Y. Zhang talk



JLAB Concept

- Initial configuration (MEIC):
  - 3-11 GeV on 20-100 GeV ep/eA collider
  - fully-polarized, longitudinal and transverse
  - luminosity: up to few x 10^{34} e-nucleons cm^{-2} s^{-1}
- Upgradable to higher energies (250 GeV protons)

A Laboratory for Nuclear Science



- The Jefferson Lab electron accelerator is a unique world-leading facility for nuclear physics research
- 12 GeV upgrade ensures at least a decade of excellent opportunities for discovery
  - New vistas in QCD
  - Growing program Beyond the Standard Model
- EIC moving forward:
  - Strong science case, much builds on JLab 12 GeV program
  - MEIC design well developed – time scale following 12 GeV program is “natural”
- Other topics not covered in this presentation:
  - Theory and Computation
  - Accelerator Science and Technology
  - Medical Imaging applications

Backups

Hall Operating Scenarios (R. Ent)

Includes approved experiments by the Program Advisory Committee (PAC) only
PAC-days per year = weeks of operations × 7 × multiplicity × 0.5

Flat scenario	Reduction of scientific capabilities Long delay in benefit of investments 175 PAC days per year 17.5 (14) year backlog (number between parentheses is without Moller and SOLID)
Constant-Effort	Complementary scientific capabilities Delay in parts of 12-GeV program 262 PAC days per year 11.7 (9.2) year backlog
Proposed	Enhancements to scientific capabilities 12 GeV with full capabilities after CD-4b 368 PAC days per year 8.3 (6.6) year backlog